Bhardwaj *et al. J Anesth Analg Crit Care* (2025) 5:65
https://doi.org/10.1186/s44158-025-00283-6

Journal of Anesthesia, Analgesia and Critical Care

RESEARCH

Open Access

Dual doppler dynamics: integrating femoral venous doppler and VExUS for predicting organ dysfunction in acute heart failure

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Abstract

Background Heart failure (HF) leads to venous congestion (VC), leading to organ dysfunction. Traditional VC assessments include pulmonary artery catheterization and IVC ultrasound. Newer tools like venous excess ultrasound (VExUS) and femoral venous doppler (FVD) quantify VC severity. We aimed to compare FVD with VExUS score to predict organ dysfunction and its progression in acute HF patients.

Methods We conducted a 6-month prospective study in a 36-bed Cardiac ICU, enrolling 111 adults with acute decompensated HF. We evaluated FVD and VExUS to predict organ dysfunction and its progression. Key parameters were recorded on ICU admission and Day 3. We followed up patients at 90-days using the MAKE-90 criteria. Sensitivity, specificity, and predictive values of FVD and VExUS were calculated and compared using McNemar's test.

Results VC was higher in the organ dysfunction group, with higher VExUS scores (55% vs. 31%, $p=0.018$) and FVD-defined congestion (85% vs. 57%, $p=0.002$). This group also revealed worse LUS, lower TAPSE:PASP ratios, more severe AKI, higher creatinine, and increased use of non-invasive ventilation (all $p<0.01$). Mortality (39% vs. 24%) and MAKE-90 events (56% vs. 39%) were higher but not statistically significant. FVD had higher sensitivity but lower specificity than VExUS in detecting AKI, and lung congestion. VExUS had higher specificity for RV coupling and organ dysfunction; FVD correlated more with organ dysfunction.

Conclusion FVD and VExUS provide complementary insights into venous congestion, reinforcing the need for an integrated approach rather than reliance on a single modality. A multimodal strategy combining these tools with clinical and biochemical markers may offer a more precise framework for guiding management in acute heart failure.

Trial registration This trial was registered with Clinical Trial Registry-India (https://www.ctri.nic.in/), Trial No—CTRI/2023/10/058186 on 3/10/2023.

Keywords Venous congestion, Venous excess ultrasound, Femoral venous doppler, Organ dysfunction, Acute kidney injury

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Background

Heart failure (HF) is one of the leading cardiac causes of hospitalization in India, affecting approximately 1% of the general population annually and contributing to nearly 10 million cases, according to the National Heart Failure Registry of India [1]. Acute or decompensated HF presents with sudden deterioration in symptoms, necessitating hospital admission [2]. Regardless of the underlying cause, venous congestion (VC) is a hallmark of acute HF, leading to organ dysfunction including pulmonary edema, acute kidney injury (AKI), and hepatic impairment due to inadequate perfusion. Persistent VC is also associated with chronic congestive hepatopathy and progressive renal dysfunction, particularly in patients with pulmonary hypertension [3] therefore, accurate assessment and mitigation of VC is crucial.

Traditionally, pulmonary artery catheterization and cardiac output monitoring have been employed as surrogates of VC [4, 5]. Lung ultrasonography and inferior vena cava (IVC) assessment are also established approaches. More recently, venous excess ultrasound (VExUS) and femoral venous Doppler (FVD) have emerged as objective, Doppler-based tools to quantify congestion [6].

FVD, a newer modality, is technically easier to perform compared to VExUS [7, 8]. The common femoral vein drains directly into the IVC; hence, it effectively transmits pressure changes with worsening congestion [9]. FVD has been studied for its diagnostic potential, including its role in developing congestion assessment algorithms and detecting right ventricular dysfunction in certain groups of patients [7].

The simplicity and feasibility of FVC assessment holds promise as a tool to assess VC severity and predict organ dysfunction [10]. This may facilitate treatment optimization, targeting FVD normalization for improved outcomes among patients with HF. However, no prospective studies have evaluated its utility in acute HF.

We aimed to evaluate FVD compared with VExUS score in predicting the organ dysfunction and its progression in acute HF patients. Organ dysfunction was defined by a lung ultrasound score (LUS) > 15 and/or AKI stage 2 or higher, among patients admitted to a cardiac intensive care unit (CICU).

Methods

Ethics approval

The Narayana Health Academic Ethics Committee (Approval #NHH/AEC-CL-2023–1008; August 2023) approved the conduct of this study. This trial was registered with Clinical Trial Registry-India (https://www.ctri.nic.in/), Trial Number—CTRI/2023/10/058186 on 3/10/2023. Informed consent was obtained from the patient before the screening/recruitment process. Patients who declined participation were excluded from the study.

Reporting guideline adherence

This study was designed and reported as per the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

Setting, participants, and design

We conducted a prospective observational study over 6 months (November 2023–April 2024) in the 36-bedded CICU of a large tertiary care hospital in Bengaluru, India. Our CICU specializes in the management of patients with HF, acute coronary syndromes, pre- and post-heart transplant care, and malignant arrhythmias.

The primary objective was to compare FVD with VExUS to predict organ dysfunction and its progression in acute HF patients. Organ dysfunction was defined by LUS > 15 and/or AKI stage 2 or more in patients with acute HF. This definition of organ dysfunction was intended to better capture patients with meaningful and prognostically relevant end-organ impairment in the setting of acute HF, aligning with current clinical evidence and expert consensus [11–14]. Secondary objectives included comparison of VC severity through serial FVD, assessment of its prognostic value in acute HF, and evaluate its correlation with right ventricular function for a detailed hemodynamic evaluation.

Eligibility criteria

Adult patients aged 18 years or older admitted to the CICU with acute HF, characterized by a recent worsening of shortness of breath, oxygen saturation (SpO_2) < 90% on room air, or symptoms of orthopnea/paroxysmal nocturnal dyspnea (PND), accompanied by an elevated NT-proBNP level were included [15, 16].

We excluded patients with conditions that could confound hemodynamic assessment or compromise study feasibility. Patients on invasive mechanical ventilation, those with altered mentation, or requiring Renal Replacement Therapy (RRT) were excluded. Those requiring two or more vasoactive agents, mechanical circulatory support, presenting with severe arrhythmias (HR < 40 bpm), non-cardiac conditions necessitating critical care admission, patients with directives for comfort care, liver cirrhosis with severe ascites (grade 3), and pregnant patients were also excluded [17].

FVD and VExUS assessments were performed on ICU admission (day 1) and day 3, along with bedside 2D echocardiography to evaluate right ventricular-pulmonary artery systolic pressure (RV-PASP) uncoupling. Congestion parameters—including LUS, serum creatinine, fluid

balance, and pedal edema—were recorded at each time point. A 90-day telephonic follow-up using the MAKE-90 criteria (readmission, need for dialysis, and death) was conducted.

AKI was classified per the Kidney Disease: Improving Global Outcomes (KDIGO) guidelines: Stage 1 (1.5–1.9 × serum creatinine (SCr) increase or oliguria for 6–12 h), Stage 2 (2.0–2.9 × SCr rise or oliguria for ≥ 12 h); and Stage 3 (≥ 3.0 × SCr rise, SCr ≥ 4.0 mg/dL, need for dialysis, or severe oliguria/anuria) [18]. These criteria guided AKI severity classification and clinical management.

Techniques for assessment

VExUS, FVD, and lung ultrasound were done by one experienced intensivist with at least 3 years of experience in critical care ultrasonography, certified after a training and assessment program. The assessor was a part of the clinical management team. All scans were performed in the supine position using a Philips CX50 model ultrasound machine.

Right ventricle—pulmonary artery (RV-PA) uncoupling

Tricuspid annular plane systolic excursion (TAPSE) was tracked in the RV-focused apical 4-chamber view using M-mode echocardiography.

PASP (mm Hg) was calculated as follows:

x [peak velocity of tricuspid regurgitation]^2 + [estimated right atrial pressure]

The pressure measurement was based on the IVC diameter and collapsibility. Patients without noticeable TR signal or lacking inspiratory/expiratory phases of IVC diameters were excluded. A ratio of 0.31 was considered as a metric for uncoupling [19]. Patients with a suboptimal echo window for estimation of PASP and TAPSE were excluded from the study (Fig. 1).

VExUS assessment

Ultrasound assessment was performed by the bedside using a Phillips CX50 ultrasound machine, with the use of a cardiac probe (1–5 MHz). Patients were positioned in the dorsal decubitus position with the head end elevated at 30°. Hepatic venous Doppler was performed, visualizing either the middle hepatic vein in the subxiphoid area or the right hepatic vein from a lateral angle. Similarly, the portal vein Doppler was interrogated through a lateral approach. All Doppler examinations were recorded and measured at end-expiration during respiratory pause [20].

FVD congestion assessment

The FVD was obtained with the patient in the supine position with a linear array probe. The common femoral vein was identified 2–3 cm below the inguinal ligament and examined in the short and long axis views with an angle correction within 60°. Normal FVD (non-congested) was defined as antegrade mildly pulsatile uninterrupted pattern with respiratory variation and retrograde flow of less than 1/3rd of antegrade flow.

FVD was considered significant (congested) or suggestive of venous congestion if any of the following criteria were met:

1. Pulsatile in nature (more than 50% pulsatility)

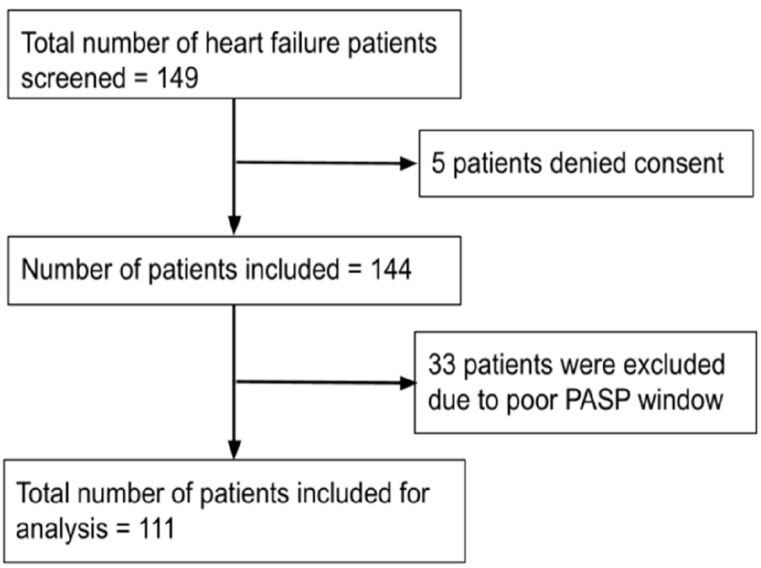
Total number of heart failure patients screened = 149
5 patients denied consent
Number of patients included = 144
33 patients were excluded due to poor PASP window
Total number of patients included for analysis = 111

Fig. 1 STROBE diagram

2. Retrograde flow velocity of more than 10 cm/s
3. Retrograde flow velocity being more than 1/3rd of antegrade flow velocity (flow reversal) [20].

Thoracic imaging

We used point of care ultrasound (POCUS) to assess congestion and cardiac dysfunction. Lung ultrasound detected B-lines and pleural effusion, indicating fluid overload. We employed a 12-zone lung ultrasound scoring (LUS) system, evaluating 6 zones per lung to quantify B-lines and assess pulmonary congestion. Each lung zone was assigned a score based on the number and pattern of B-lines observed:

- Score 0: ≤ 2 B-lines (normal lung aeration).
- Score 1: ≥ 3 B-lines (mild interstitial involvement).
- Score 2: Multiple coalescent B-lines or multiple small subpleural consolidations (moderate congestion).
- Score 3: Dense coalescent B-lines or lung consolidation (white lung, severe congestion) [21].

Abnormal FVD was defined according to the criteria proposed by Denault et al., which characterize abnormal flow as a loss of normal phasicity or reversal of systolic flow. These criteria were chosen as they are physiologically grounded in the transmission of elevated right atrial pressures into large central veins and have been previously validated in critically ill populations as markers of venous congestion and adverse outcomes [7].

2D echocardiography provided a detailed evaluation of cardiac function, revealing LV systolic and diastolic dysfunction, RV dysfunction, acute valve disease, aortic flap, pericardial effusion, interventricular defects, and IVC measurements.

Pedal edema was assessed using the standard pitting edema grading technique, which involves applying firm pressure over the dorsum of the foot or near the medial malleolus for a few seconds and observing the depth and duration of the resulting indentation. The grading scale ranges from 0 to 4, with 0 showing no edema and 1 indicating barely detectable pitting that resolves quickly, and 4 representing deep, prolonged pitting with visible distortion of the foot or ankle.

Clinical management

All patients with acute heart failure were clinically managed to improve organ perfusion focusing on reducing fluid overload and improving hemodynamics. Loop diuretics served as the cornerstone therapy for relieving congestion and associated symptoms. For clarity, the diuretic regimen has been illustrated in the Supplementary File (Figure S1). In cases of diuretic resistance, combination therapy with thiazides or the use of ultrafiltration were considered [22]. Fluid status and organ functions were monitored continuously. Therapy was adjusted based on clinical response. NIV and invasive mechanical ventilation were used as per standard indications for heart failure [16]. In patients exhibiting signs of tissue hypoperfusion (e.g., cold and clammy peripheries, rising lactate levels, or oliguria), inotropic support was initiated. Dobutamine (3–5 µg/kg/min) or Milrinone (0.375 µg/kg/min) was considered, with or without the addition of a norepinephrine infusion, to maintain a mean arterial pressure (MAP) of 60–65 mmHg.

Sample size calculation

We calculated the sample size based on the following formula: [23].

Formula: $n = [Z^2 1\text{-}a/2\ p\ (1—p)]/d.^2$

p: expected proportion
d: absolute precision

1-a/2: desired confidence level.

In our previous study, the incidence of AKI was 46.7% [20]. Expecting an incidence of organ dysfunction of 11% of the overall study (~ 30% of patients with AKI) and with an expected sensitivity of 95% (for VExUS and FVD) with a precision of 10%, the required sample size is 110 patients [24].

Statistical analysis plan

Categorical variables were presented as absolute counts and percentages. The normality of continuous variables was assessed using the Shapiro–Wilk test. Depending on the results, continuous data were reported as mean and standard deviation (SD) for normally distributed variables or median and interquartile range (IQR) for non-normally distributed variables. There were no missing data for the variables included in the analysis; therefore, no imputation was required. Comparisons between patient groups were conducted using the chi-square test or Fisher's exact test for categorical variables, depending on expected frequencies in contingency tables. For continuous variables, either Student's *t*-test or the Wilcoxon–Mann–Whitney rank-sum test was used based on the normality of the distribution.

Sensitivity, specificity, positive predictive value, and negative predictive value of FVD and VExUS for predicting organ dysfunction were calculated, and the comparison of both tests was performed using McNemar's test. Changes in FVD and VExUS trends between

the day of admission and day 3 were analyzed in relation to the onset of AKI alone and organ dysfunction. To assess whether the direction of change in FVD and VExUS (e.g., normal to abnormal, abnormal to normal) was associated with corresponding changes in clinical outcomes, we used Cohen's Kappa coefficient to evaluate the concordance between the venous congestion trends and the trends of AKI alone and organ dysfunction, respectively. We conducted exploratory analyses to assess the association of FVD and VEXUS variables with mortality and MAKE-90 (Supplementary document). A *p*-value less than 0.05 was considered statistically significant.

Results

The study population included 111 patients with a mean (SD) age of 58 years [14], and 79% were male. The mean (SD) Get With The Guidelines (GWTG) HF Risk Score for in-hospital mortality was 44 [8], corresponding to a predicted in-hospital mortality rate of 1–5%, which closely aligned with our observed in-hospital mortality rate of 6.3% [25]. Among the cohort, 63% had diabetes mellitus (DM), and 63% had hypertension (HTN). Chronic kidney disease (CKD) was present in 21% of patients, with a significantly higher prevalence in the organ dysfunction group compared to the non-organ dysfunction group (31% vs. 8.2%, $p=0.008$). VExUS score of 1 or more (indicating congestion) was observed in 44% of the cohort; it was observed significantly more often in the organ dysfunction group compared to the non-organ dysfunction group (55% vs. 31%, $p=0.018$). Similarly, FVD-defined congestion was present in 73% of patients, with a higher incidence in the organ dysfunction group (85% vs. 57%, $p=0.002$). Pedal edema grading showed no statistically significant differences between groups ($p=0.082$).

The organ dysfunction group exhibited significantly higher lung ultrasound scores (23 [IQR 12–24] vs. 12 IQR [10–12], $p<0.001$) and lower TAPSE:PASP ratios (0.32 [IQR 0.24–0.46] vs. 0.39 [IQR 0.29–0.62], $p=0.010$) compared to the non-organ dysfunction group. This group also had more severe AKI stages, higher creatinine levels (1.61 [IQR 1.17–2.89] vs. 1.10 [IQR 0.80–1.24], $p<0.001$), and greater use of non-invasive ventilation (23% vs. 4.1%, $p=0.006$). Although there were no significant differences in RRT, sepsis, length of ICU, or hospital stay, the organ dysfunction group showed a trend towards higher mortality at 90 days of hospitalization (39% vs. 24%, $p=0.1$) and a higher incidence of MAKE-90 events (52% vs. 35%, $p=0.06$), although the difference was not statistically significant (Table 1).

Diagnostic accuracy of VEXUS score and FVD

The McNemar test revealed a statistically significant difference between FVD and VExUS in classifying venous congestion ($p<0.001$). FVD identified a higher number of patients as abnormal compared to VExUS, as shown by the asymmetry in discordant classifications: 36 cases were abnormal by FVD but normal by VExUS, while only 4 were abnormal by VExUS but normal by FVD. This suggests that FVD may be more sensitive—or potentially less specific—than VExUS in detecting venous congestion.

At 24 h, among patients with AKI (Stage 2 or 3), the VExUS score revealed limited diagnostic accuracy, with low sensitivity (45.00%; 95% CI, 32.12–58.39%) and moderate specificity (56.86%; 95% CI, 42.25–70.65%). The positive likelihood ratio was modest (+LR, 1.04; 95% CI, 0.68–1.59). The FVD assessment on day 1 showed greater sensitivity [78.33% (95% CI, 65.80–87.93%)] but reduced specificity [33.33% (95% CI, 20.76–47.92%)] and yielded a marginally higher +LR [1.17 (95% CI, 0.93–1.49)]; there is no difference between both tests to predict AKI (McNemar's test $p=0.27$) (details are depicted in Table 2).

In regard to lung congestion (LUS > 15), the VExUS score on day 1 showed moderate sensitivity [56.82%, (95% CI, 41.03–71.65%)] and specificity [(64.18%, (95% CI, 51.53–75.53%)], with a +LR of 1.59 (95% CI, 1.05–2.39) and a diagnostic odds ratio (DOR) of 2.36 (95% CI, 1.08–5.13). In contrast, the FVD on day 1 demonstrated superior sensitivity [95.45%, (95% CI, 84.53–99.44%)] but lower specificity [41.79%, (95% CI, 29.85–54.48%)], with a +LR of 1.64 (95% CI, 1.33–2.03) and a DOR of 15.08 (95% CI, 3.37–67.52). For pedal edema presence (grade 2 or 3), VExUS showed moderate sensitivity [52.31%, (95% CI, 39.54–64.85%)] and specificity [67.39%, (95% CI, 51.98–80.47%)], while FVD provided higher sensitivity [86.15%, (95% CI, 75.34–93.47%)] but lower specificity [45.65%, (95% CI, 30.90–60.99%)] and no difference between both tests in both the results (McNemar's test of 0.87 and 0.08 respectively) (Table 2).

The VExUS score demonstrated moderate diagnostic performance for the assessment of RV coupling on day 1, with a sensitivity of 70.21% (95% CI, 55.11–82.66%) and a specificity of 75.00% (95% CI, 62.60–84.98%). These parameters translated into a positive likelihood ratio (+LR) of 2.81 (95% CI, 1.77–4.46), a negative likelihood ratio (−LR) of 0.40 (95% CI, 0.25–0.63), with an overall accuracy of 73%. In contrast, FVD assessment for RV coupling showed superior sensitivity at 93.62% (95% CI, 82.46–98.66%) but a markedly lower specificity at 42.19% (95% CI, 29.94–55.18%). The findings of FVD yielded a +LR of 1.62 (95% CI, 1.30–2.02), with a notable −LR

Table 1 Demographic, clinical data at recruitment and outcome data

Variable	Overall, $N=111$[1]	Not organ dysfunction, $N=49$[1]	Organ dysfunction, $N=62$[1]	p-value[2]
Age	58 (14)	56 (13)	59 (14)	0.2
Sex (male)	88 (79%)	35 (71%)	53 (85%)	0.11
GWTG score	44 (8)	43 (7)	45 (9)	0.10
DM	70 (63%)	28 (57%)	42 (68%)	0.3
HTN	70 (63%)	30 (61%)	40 (65%)	0.9
CKD	23 (21%)	4 (8.2%)	19 (31%)	**0.008**
COPD	14 (13%)	7 (14%)	7 (11%)	0.9
VExUS (congestion)	49 (44%)	15 (31%)	34 (55%)	**0.018**
FVD (congestion)	81 (73%)	28 (57%)	53 (85%)	**0.002**
Grade of pedal edema				0.082
0	13 (12%)	3 (6.1%)	10 (16%)	
1	33 (30%)	19 (39%)	14 (23%)	
2	51 (46%)	24 (49%)	27 (44%)	
3	12 (11%)	3 (6.1%)	9 (15%)	
4	2 (1.8%)	0 (0%)	2 (3.2%)	
Lung ultrasound score	12 [12, 24]	12 [10, 12]	23 [12, 24]	**< 0.001**
TAPSE: PASP	0.34 [0.26, 0.53]	0.39 [0.29, 0.62]	0.32 [0.24, 0.46]	**0.010**
RV uncoupling	47 (42%)	17 (35%)	30 (48%)	0.2
LVEF	35 [25, 45]	35 [25, 45]	35 [25, 44]	0.9
Dyskinetic septum	19 (17%)	5 (10%)	14 (23%)	0.086
AKI				**< 0.001**
0	51 (46%)	33 (67%)	18 (29%)	
1	32 (29%)	16 (33%)	16 (26%)	
2	13 (12%)	0 (0%)	13 (21%)	
3	15 (14%)	0 (0%)	15 (24%)	
Fluid balance	−600 [−1,021, −259]	−650 [−1109, −400]	−507 [−1000, −85]	0.2
Creatinine	1.24 [0.88, 1.92]	1.10 [0.80, 1.24]	1.61 [1.17, 2.89]	**< 0.001**
Invasive ventilation	10 (9.0%)	2 (4.1%)	8 (13%)	0.2
NIV	16 (14%)	2 (4.1%)	14 (23%)	**0.006**
RRT	9 (8.1%)	1 (2.0%)	8 (13%)	0.075
Sepsis[3]	5 (4.5%)	3 (6.1%)	2 (3.2%)	0.7
MAKE 90	49 (44%)	17 (35%)	32 (52%)	0.06
Re-hospitalization (MAKE 90)	33 (30%)	12 (24%)	21 (34%)	0.26
Dialysis (MAKE 90)	4 (3.6%)	1 (2.0%)	3 (4.8%)	0.43
Mortality (MAKE90)	36 (32%)	12 (24%)	24 (39%)	0.11
ICU LOS	5.00 [4.00, 7.00]	5.00 [4.00, 7.00]	5.50 [4.00, 7.75]	> 0.9
HOSPITAL LOS	7 [5, 9]	7 [5, 10]	7 [5, 9]	> 0.9

Abbreviations: *GWTG* Get with the guidelines, *DM* Diabetes mellitus, *HTN* Hypertension, *CKD* Chronic kidney disease, *COPD* Chronic obstructive pulmonary disease, *RV* Right ventricle, *LVEF* Left ventricular ejection fraction, *AKI* Acute kidney injury, *RRT* Renal replacement therapy, *NIV* Non-invasive ventilation, *MAKE 90* Major adverse kidney event within 90 days, *LOS* Length of stay

[1] Mean (SD), *n* (%), Median [IQR]

[2] Welch Two Sample t-test, Pearson's Chi-squared test, Fisher's exact test, Wilcoxon rank sum test

[3] Sepsis was defined as per the latest Surviving Sepsis Guidelines [26]

Data in bold are statistically significant, $P < 0.05$

of 0.15 (95% CI, 0.05–0.47); (McNemar's test $p=0.15$). Additionally, patients with abnormal FVD had significantly lower TAPSE values (14.0 mm [13.0–15.7]) compared to those with normal FVD (16.0 mm [14.0–19.0], $p<0.001$), indicating an association between FVD abnormalities and reduced RV systolic function.

Table 2 Diagnostic accuracy of VExUS score and FVD

Test	Overall, (*n* = 111)	Sensitivity % (95% CI)	Specificity % (95% CI)	PPV % (95% CI)	NPV % (95% CI)	LR (CI)	LN (CI)	Accuracy (CI)	Diagnostic odds ratio (CI)
VExUS score	**AKI (grade 2 or 3)**	45.00 (32.12, 58.39)	56.86 (42.25, 70.65)	0.55 (0.40, 0.69)	0.47 (0.34, 0.60)	1.04 (0.68, 1.59)	0.97 (0.69, 1.35)	0.50 (0.41, 0.60)	1.08 (0.51, 2.29)
	Lung congestion (LUS > 15)	56.82 (41.03, 71.65)	64.18 (51.53, 75.53)	0.51 (0.36, 0.66)	0.69 (0.56, 0.80)	1.59 (1.05, 2.39)	0.67 (0.46, 0.99)	0.61 (0.52, 0.70)	2.36 (1.08, 5.13)
	Grade of pedal Edema (2, 3)	52.31 (39.54, 64.85)	67.39 (51.98, 80.47)	0.69 (0.55, 0.82)	0.50 (0.37, 0.63)	1.60 (1.00, 2.58)	0.71 (0.51, 0.98)	0.59 (0.49, 0.68)	2.27 (1.03, 4.97)
FVD	**AKI (grade 2 or 3)**	78.33 (65.80, 87.93)	33.33 (20.76, 47.92)	0.58 (0.47, 0.69)	0.57 (0.37, 0.75)	1.17 (0.93, 1.49)	0.65 (0.35, 1.21)	0.58 (0.48, 0.67)	1.81 (0.78, 4.21)
	Lung congestion (LUS > 15)	95.45 (84.53, 99.44)	41.79 (29.85, 54.48)	0.52 (0.40, 0.63)	0.93 (0.78, 0.99)	1.64 (1.33, 2.03)	0.11 (0.03, 0.43)	0.63 (0.53, 0.72)	15.08 (3.37, 67.52)
	Grade of pedal Edema (2, 3)	86.15 (75.34, 93.47)	45.65 (30.90, 60.99)	0.69 (0.58, 0.79)	0.70 (0.51, 0.85)	1.59 (1.20, 2.10)	0.30 (0.15, 0.60)	0.69 (0.60, 0.78)	5.23 (2.10, 13.01)

The VExUS score exhibited limited sensitivity for the detection of organ dysfunction on day1 (54.84%; 95% CI, 41.68–67.52%) but moderate specificity (69.39%; 95% CI, 54.58–81.75%), resulting in a + LR of 1.79 (95% CI, 1.11–2.89) and a − LR of 0.65 (95% CI, 0.47–0.91). In contrast, FVD assessment demonstrated a higher sensitivity (85.48%; 95% CI, 74.22–93.14%) but lower specificity (42.86%; 95% CI, 28.82–57.79%), achieving a + LR of 1.50 (95% CI, 1.15–1.95) (McNemar's test *p*-value = 0.43), (details in Table 3).

Analyses of trends

The analysis of organ dysfunction revealed a modest agreement between the trend in FVD and organ dysfunction, with a statistically significant Cohen's Kappa coefficient of 0.20 (95% CI, 0.07–0.34), ($p = 0.003$). In contrast, the VExUS trend demonstrated minimal agreement with organ dysfunction, as reflected by a Cohen's Kappa coefficient of 0.09 (95% CI, 0.00–0.21), which did not reach statistical significance ($p = 0.156$). In regard to the trend in AKI, a very low agreement was observed between FVD and AKI, with a Cohen's Kappa coefficient of 0.08 (95% CI, 0.001–0.16), ($p = 0.047$). Similarly, the VExUS trend demonstrated minimal agreement with AKI, with a Cohen's Kappa coefficient of 0.06 (95% CI, 0.00–0.15) ($p = 0.147$).

Exploratory analysis

In exploratory analyses (Tables S1–S2), age and lower LVEF were consistently associated with higher mortality risk, while sex and GWTG score were not significant predictors. Neither baseline FVD nor VExUS grades showed significant associations with mortality or MAKE-90, although point estimates suggested a possible trend toward increased odds of mortality with congestion evaluated by FVD (multivariable OR 2.65, 95% CI 0.92–8.62; $p = 0.084$). Trend analyses for both FVD and VExUS did not demonstrate significant associations with outcomes, although patients with persistently normal FVD values showed a nonsignificant trend toward lower mortality risk (OR 0.30, 95% CI 0.07–1.02; $p = 0.068$).

Table 3 Diagnostic accuracy of VExUS/FVD score

Test	Overall, (*n* = 111)	Sensitivity % (95% CI)	Specificity % (95% CI)	PPV % (95% CI)	NPV % (95% CI)	LR (CI)	LN (CI)	Accuracy (CI)	Diagnostic odds ratio (CI)
VExUS score	**RV coupling**	70.21 (55.11, 82.66)	75.00 (62.60, 84.98)	0.67 (0.52, 0.80)	0.77 (0.65, 0.87)	2.81 (1.77, 4.46)	0.40 (0.25, 0.63)	0.73 (0.64, 0.81)	7.07 (3.04, 16.43)
	Organ dysfunction	54.84 (41.68, 67.52)	69.39 (54.58, 81.75)	0.69 (0.55, 0.82)	0.55 (0.42, 0.68)	1.79 (1.11, 2.89)	0.65 (0.47, 0.91)	0.61 (0.52, 0.70)	2.75 (1.25, 6.05)
FVD	**RV coupling**	93.62 (82.46, 98.66)	42.19 (29.94, 55.18)	0.54 (0.43, 0.65)	0.90 (0.73, 0.98)	1.62 (1.30, 2.02)	0.15 (0.05, 0.47)	0.64 (0.54, 0.73)	10.70 (3.00, 38.13)
	Organ dysfunction	85.48 (74.22, 93.14)	42.86 (28.82, 57.79)	0.65 (0.54, 0.76)	0.70 (0.51, 0.85)	1.50 (1.15, 1.95)	0.34 (0.17, 0.67)	0.67 (0.57, 0.75)	4.42 (1.79, 10.92)

Discussion

VC is a major driver of organ dysfunction in HF, particularly impacting the kidneys and lungs. Both VExUS and FVD provide valuable insights into systemic congestion through assessment of venous waveforms at different anatomical sites. These imaging techniques play a pivotal role in identifying congestion and cardiac abnormalities, contributing to a comprehensive assessment. While prior studies have established an association between FVD and VExUS, no definitive evidence exists regarding their comparative effectiveness in predicting organ dysfunction and its progression.

Our study provides a comparative analysis of FVD and VExUS in the assessment of VC and its potential impact on organ dysfunction in acute HF. Our findings suggest that FVD, compared to VExUS is a more sensitive tool to detect congestion associated with organ dysfunction, enabling early identification of VC. However, both techniques showed only a moderate correlation with AKI trends, likely due to the delayed serum creatinine response and the multifactorial nature of AKI.

More patients were classified as congested using FVD compared to VExUS. This discrepancy reflects fundamental physiological differences between the two tools: FVD, as a conduit venous Doppler, primarily transduces right atrial pressure pulsatility and therefore becomes abnormal earlier, explaining its greater sensitivity. In contrast, VExUS integrates multiple abdominal venous Doppler patterns, capturing the downstream effects of elevated central venous pressure once organ capacitance is exceeded, thereby providing greater specificity for clinically significant venous congestion.

The presence of congestion, as evident on POCUS, revealed a higher LUS, more severe AKI, and reduced RV function, suggesting that VC is not merely a marker of fluid overload but a key contributor to multi-organ dysfunction. The higher prevalence of FVD-defined congestion compared to VExUS suggests that IVC-based assessments may underestimate VC in certain populations, particularly those with obesity or altered intrathoracic pressures [27].

Thus, FVD may be better conceptualized as a sensitive screening tool for identifying patients "at risk" of venous congestion, whereas VExUS serves as a confirmatory method for diagnosing established, hemodynamically significant organ congestion. This complementary role aligns with recent frameworks on venous congestion phenotyping [28]. This suggests that while FVD is effective in ruling out congestion, VExUS may offer additional specificity in confirming clinically significant congestion. This may be explained by multiple venous examinations being incorporated into a composite scoring system in VExUS [29].

A key advantage of FVD over VExUS is its ease of acquisition, requiring minimal patient repositioning, making it more practical in the critically ill or obese patients. Additionally, FVD is more effective in detecting early congestion before severe organ dysfunction manifests and is less affected by IVC collapsibility variations, which can lead to underestimation of congestion in VExUS assessments.

A retrospective study on acute HF by Sarijaloo et al. reported a 15.2% readmission rate due to HF and 11.5% mortality within 90 days of discharge [30]. Their findings identified a dilated IVC as a key risk factor for readmission and mortality, corroborating with our findings. However, our study observed higher rates of MAKE-90 (44%), including a 30% readmission rate and 32% mortality, suggesting a greater burden of congestion-related complications in our cohort. These differences may stem from variations in patient populations, study designs, and baseline congestion severity, further emphasizing the prognostic significance of IVC dilatation.

This study also highlights the potential impact of VC on key clinical outcomes, including rehospitalization, dialysis dependence, mortality, and long-term renal function. While VC assessment provides critical insights, its predictive value remains uncertain, underscoring the multifactorial nature of these outcomes. Rehospitalization appeared to be influenced by additional clinical factors apart from congestion, emphasizing the need for a more comprehensive risk assessment. Dialysis requirements remained low, indicating that congestion may not be the sole determinant of worsening kidney function. Mortality trends suggested a possible association with the severity of congestion, although it fell short of statistical significance. Similarly, adverse kidney events followed a pattern warranting further investigation into the role of congestion in renal dysfunction.

Despite these findings, the lack of statistically significant differences underscores the need for larger, prospective studies. Incorporating serial congestion monitoring and a multimodal assessment approach may enhance risk stratification and optimize treatment strategies for patients with acute HF and AKI.

A notable observation in our study was the weak correlation between congestion trends and the progression of AKI. This discrepancy may stem from the delayed creatinine response in AKI compared to real-time changes in congestion. Furthermore, congestion is highly dynamic, influenced by fluid shifts and therapeutic interventions,

making single-time-point assessments less predictive of long-term renal outcomes.

Also, two time-point assessments (48 h apart in our study) could likely have underestimated the cumulative "congestion burden." This could potentially explain the very weak yet statistically significant concordance between Doppler trajectories and outcomes (Cohen's Kappa = 0.20). The low Kappa underscores that the association is insufficient for patient-level decision-making, highlighting the need for future studies with more frequent, serial assessments in line with recent calls for dynamic, therapy-guided hemodynamic monitoring.

Our results indicate that FVD provides incremental diagnostic value in assessing VC. Future research should focus on integrating FVD with VExUS for multimodal congestion assessment, and exploring real-time FVD monitoring for guiding fluid removal strategies in HF patients. Furthermore, the question whether titrating HF or AKI treatments based on serial VExUS/FVD trends improves clinical outcomes needs to be addressed. A prospective study with higher sampling frequency and a comprehensive congestion assessment—including central venous pressure (CVP), renal Doppler, and urine output trends—is essential for validating these tools in clinical practice.

Limitations

Despite the putative advantages of FVD over VExUS, both have inherent limitations in accurately predicting AKI and lung congestion trends. The dynamic nature of congestion causes rapid fluctuations in venous waveforms due to fluid shifts, making single-time-point assessments unreliable. Additionally, sampling limitations with measurements only on admission day and day 3 may fail to capture frequent volume status changes, necessitating more frequent monitoring. The lack of CVP could also limit the validation of congestion severity, as many patients did not require central venous catheters. Moreover, the classification of AKI severity relied on serum creatinine, which lags behind real-time kidney dysfunction, potentially underestimating early-stage AKI compared to urine output measurements. Also, the exclusion of 23% of patients due to poor acoustic windows may have introduced selection bias, and the single-center cardiac ICU setting limits generalizability, particularly for the TAPSE:PASP ratio findings.

Another limitation of these exploratory analyses is that the study was not powered to detect differences in mortality or MAKE-90. The limited number of events reduces the precision of estimates and increases the risk of type II error, meaning that potentially meaningful associations may not have reached statistical significance. As such, the observed trends should be regarded as hypothesis-generating rather than definitive.

Conclusion

In our study, FVD demonstrated greater sensitivity for severe AKI prediction while VExUS offered additional specificity, underscoring their distinct but synergistic diagnostic contributions. Rather than viewing one tool as superior, our findings support a multimodal approach—combining FVD, VExUS, and other clinical/biochemical markers to optimize congestion assessment and clinical decision-making in acute HF.

Abbreviations

HF	Heart failure
VC	Venous congestion
FVD	Femoral venous doppler
VExUS	Venous excess ultrasound
CICU	Cardiac intensive care unit
LUS	Lung ultrasound score
AKI	Acute kidney injury
RV	Right ventricle

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s44158-025-00283-6.

Supplementary Material 1.

Acknowledgements

Not applicable.

Authors' contributions

V.B, A.S.: Conceptualization, Methodology, Project administration, Supervision, Visualization, Writing- original draft preparation, review & editing; K.S.: Data curation, Investigation, Visualization, Writing- original draft preparation, review & editing; N.O.: Formal analysis, Writing- original draft preparation, review & editing; P.H, M.N.: Investigation; J.C., A.D., P.R.,: Writing- review & editing; M.V.: Writing- review & editing, Supervision; V.G.: Formal analysis; A.A.: Project Administration, Supervision. All authors reviewed the manuscript.

Funding

No funding has been received for this study.

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The Narayana Health Academic Ethics Committee (Approval #NHH/AEC-CL-2023–1008; August 2023) approved the conduct of this study. This trial was registered with Clinical Trial Registry-India (https://www.ctri.nic.in/), Trial Number—CTRI/2023/10/058186 on 3/10/2023. Informed consent from the patient was obtained before the screening process. Patients who declined consent were not included in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Received: 23 July 2025 Accepted: 15 September 2025
Published online: 15 October 2025

References

1. ICC-NHFR [Internet]. Available from: https://www.iccnhfr.org/. Cited 2025 Apr 6
2. Kristjánsdóttir I, Thorvaldsen T, Lund LH (2020) Congestion and diuretic resistance in acute or worsening heart failure. Card Fail Rev 6:e25
3. Rosenkranz S, Howard LS, Gomberg-Maitland M, Hoeper MM (2020) Systemic consequences of pulmonary hypertension and right-sided heart failure. Circulation 141(8):678–693
4. Pinsky MR (2012) Pulmonary artery occlusion pressure. In: Pinsky MR, Brochard L, Hedenstierna G, Antonelli M, editors. Applied Physiology in Intensive Care Medicine 1: Physiological Notes-Technical Notes-Seminal Studies in Intensive Care [Internet]. Berlin, Heidelberg: Springer. p 83–6. Available from: https://doi.org/10.1007/978-3-642-28270-6_19. Cited 2025 May 18
5. Longino AA, Martin KC, Douglas IS (2024) Monitoring the venous circulation: novel techniques and applications. Curr Opin Crit Care 30(3):260–267
6. Mahmud S, Koratala A (2021) Assessment of venous congestion by Doppler ultrasound: a valuable bedside diagnostic tool for the new-age nephrologist. CEN Case Rep 10(1):153–155
7. Denault AY, Aldred MP, Hammoud A, Zeng YH, Beaubien-Souligny W, Couture EJ et al (2020) Doppler interrogation of the femoral vein in the critically ill patient: the fastest potential acoustic window to diagnose right ventricular dysfunction? Crit Care Explor 2(10):e0209
8. Abu-Yousef MM, Kakish ME, Mufid M (1996) Pulsatile venous doppler flow in lower limbs: highly indicative of elevated right atrium pressure. AJR Am J Roentgenol 167(4):977–980
9. Torres-Arrese M, Mata-Martínez A, Luordo-Tedesco D, Casasola-Sánchez G, Montero-Hernández E, Cobo-Marcos M et al (2023) Role of the femoral vein doppler in acute heart failure patients: results from a prospective multicentric study. Revista Clínica Española (English Edition) 223(6):359–365
10. Andrei S, Bahr PA, Alissant M, Saccu M, Nguyen M, Popescu BA et al (2024) Pulsatile femoral vein doppler pattern is a parameter of venous congestion in ICU patients. J Cardiothorac Vasc Anesth 38(6):1361–1368
11. Panisello-Tafalla A, Haro-Montoya M, Caballol-Angelats R, Montelongo-Sol M, Rodriguez-Carralero Y, Lucas-Noll J et al (2024) Prognostic significance of lung ultrasound for heart failure patient management in primary care: a systematic review. J Clin Med 13(9):2460
12. Mezgebu Y, Alemu S, Mohamed MA, Shibru H, Hailu W (2024) Acute kidney injury and its associated factors among patients with acute decompensated heart failure admitted to the university of Gondar Hospital, Northwest Ethiopia: a hospital-based cross-sectional study. BMC Nephrol 25(1):461
13. Ikizler TA, Parikh CR, Himmelfarb J, Chinchilli VM, Liu KD, Coca SG et al (2021) A prospective cohort study of acute kidney injury and kidney outcomes, cardiovascular events, and death. Kidney Int 99(2):456–465
14. Banerjee D, Ali MA, Wang AYM, Jha V (2025) Acute kidney injury in acute heart failure–when to worry and when not to worry? Nephrol Dial Transplant 40(1):10–18
15. Welsh P, Campbell RT, Mooney L, Kimenai DM, Hayward C, Campbell A et al (2022) Reference ranges for NT-proBNP (N-terminal pro-B-type natriuretic peptide) and risk factors for higher NT-proBNP concentrations in a large general population cohort. Circ: Heart Fail 15(10):e009427
16. Authors/Task Force Members:, McDonagh TA, Metra M, Adamo M, Gardner RS, Baumbach A et al (2022) 2021 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure: developed by the Task Force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC). With the special contribution of the Heart Failure Association (HFA) of the ESC. Eur J Heart Fail 24(1):4–131
17. Al-Busafi SA, McNabb-Baltar J, Farag A, Hilzenrat N (2012) Clinical manifestations of portal hypertension. Int J Hepatol 2012:203794
18. Kellum JA (2015) Diagnostic criteria for acute kidney injury: present and future. Crit Care Clin 31(4):621–632
19. Tello K, Wan J, Dalmer A, Vanderpool R, Ghofrani HA, Naeije R et al (2019) Validation of the tricuspid annular plane systolic excursion/systolic pulmonary artery pressure ratio for the assessment of right ventricular-arterial coupling in severe pulmonary hypertension. Circ Cardiovasc Imaging 12(9):e009047
20. Bhardwaj V, Vikneswaran G, Rola P, Raju S, Bhat RS, Jayakumar A et al (2020) Combination of inferior vena cava diameter, hepatic venous flow, and portal vein pulsatility index: venous excess ultrasound score (VEXUS score) in predicting acute kidney injury in patients with cardiorenal syndrome: a prospective cohort study. Indian J Crit Care Med 24(9):783–789
21. Sumbul HE, Koc AS, Pınar A, Aslan MZ, Gulumsek E, Koca H et al (2021) Modified lung ultrasound score in evaluating the severity of Covid-19 pneumonia. Ultrasound Med Biol 47(8):2080–2089
22. 2022 AHA/ACC/HFSA guideline for the management of heart failure: a report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines | Circulation [Internet]. Available from: https://www.ahajournals.org/doi/10.1161/CIR.0000000000001063. Cited 2025 May 21
23. Buderer NM (1996) Statistical methodology: I. Incorporating the prevalence of disease into the sample size calculation for sensitivity and specificity. Acad Emerg Med 3(9):895–900
24. Metra M, Davison B, Bettari L, Sun H, Edwards C, Lazzarini V et al (2012) Is worsening renal function an ominous prognostic sign in patients with acute heart failure? The role of congestion and its interaction with renal function. Circ Heart Fail 5(1):54–62
25. GWTG-heart failure risk score [Internet]. Available from: https://www.mdcalc.com/calc/3829/gwtg-heart-failure-risk-score. Cited 2025 Apr 6
26. Critical Care Medicine [Internet]. Available from: https://journals.lww.com/ccmjournal/fulltext/2021/11000/surviving_sepsis_campaign__international.21.aspx. Cited 2025 May 21
27. Divatia JV, Chaudhari H, Janarthanan S, M HM, Suhail S, Patil VP (2015) Agreement between inferior vena cava diameter measurements by subxiphoid versus transhepatic views. Indian J Crit Care Med 19(12):719–722
28. Vella A, Labate V, Carenini G, Alfonzetti E, Milani V, Bandera F et al (2023) Phenotyping congestion in acute heart failure by renal flow and right heart to pulmonary circulation coupling. ESC Heart Fail 10(6):3546–3558
29. Klompmaker P, Mousa A, Allard DJ, Hagen BSH, Bánki T, Vermeulen W et al (2025) The association between venous excess ultrasound grading system (VExUS) and major adverse kidney events after 30 days in critically ill patients: a prospective cohort study. J Crit Care 25(88):155097
30. Sarijaloo F, Park J, Zhong X, Wokhlu A (2021) Predicting 90 day acute heart failure readmission and death using machine learning-supported decision analysis. Clin Cardiol 44(2):230–237

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